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Abstract.

Oil extraction is the first step for further oil application even in biodiesel production. Expelling is the most common physic process in industry, which reduces the usage of chemicals that might cause the negative impact on environment even on final products. Soybean oil is the most common materials in oil industry not only for food application but in biodiesel industry. Other co-products including soybean meal and soybean hulls can be used as animal feeds. Techno-economic analysis (TEA) is used to assess the total investment and the profits of soybean oil expelling process with SuperPro Designer based on 30 million kg annual production for every 10 years from 1980 to 2014. With the fluctuation of economic, the total capital investment has been increased from 20,066,000$ to 43,347,000$ from 1980 to 2014. However, the material cost has the major effect of 63% in the final profits. The revenues from soybean oil, soybean meal and soybean hull also have been also increased with materials prices increasing from 46,706,000$ per year to 101,420,000$ per year. The gross margin of soybean oil expelling process was obtained as combining total cost and revenues, that has been increased from -2.9% to 1.5% as well.

Keywords. Soybean oil, Expelling, Techno-economic analysis, Soybean meal, Soybean hulls

Introduction

Soybean, a food rich in oil, protein and fiber, recently have had significant growth (SoyStats, 2013). Besides main product soybean oil, soybean meal and soybean hulls, coproducts, are used as a protein resources in animal feeds due to its well-balanced amino acid profile and relatively high crude protein level (Cheng and Hardy, 2003). Additionally, soybean has been gradually becoming an important resource of mineral and vitamins. The values of soybean are not only constricted in biodiesel production, but expanded to its nutrients aspect including easily digestible protein, minerals and good quality oil (Lynch et al., 1987, Corley et al., 1999, Sawada et al., 2014).

Vegetable oils are becoming an important resources not only for food, but in energy production. Soybean is the most widely planted oilseeds around the world (Cheng and Hardy, 2003). The oils generally are obtained from mechanical pressing and solvent extraction (Sawada et al., 2014). However, hexane extraction has been receiving the controversial issues due to its non-renewable fossil origins and high flammability, leading to concerns for environmental and public health (Li et al., 2004, Oliveira et al., 2013, Tabtabaei and Diosady, 2013). For expelling process, physical process, that is exempt from the risk from pollutants productions and environmental issues.

Last decades, lots of researches about different technologies of biodiesel production especially the transesterification have been reported (Freedman *et al*., 1986; Noureddini and Zhu, 1997Ranganathan *et al*., 2007, Fukuda, 2001, Watanabe *et al*., 2000, Chen *et al*., 2003, Hama *et al*., 2007). Besides technical point of view, economics feasibility also plays an important role in process. However, there were large amounts of research studying on different raw materials, processes and production scales. Koutinas *et al*., (2014) compared homogeneous and heterogeneous procedures of transesterification. Marchetti and Errazu, (2008) analyzed the supercritical biodiesel production. Nelson et al., (1994) conducted economic analysis of 100,000 ton/year biodiesel with beef tallow and methanol by acid catalysis. A similar study was performed by Noordam and Withers (1996) using canola seeds. Additionally, there were still other different economics modeling analyses for biodiesel production with different software (Bender, 1999, Zhang *et al*., 2003, Marchetti *et al*., 2008, Mlay *et al*., 2014).

According to biodiesel production, oil extraction is the first step of the whole process. The biodiesel production model can be regarded as a proper reference for model establishment of oil extraction model. The goal for plant and commercial scale production is to lower the capital investment and operation cost but still maintaining the same product quality to gain more profits. Each process unit can effluence the others, and it can be seen as another type of chain reaction. Oil extraction playing the first process unit, which also defines the profit of the producing line. For the economic analysis of oil extraction, co-products play another critical factor for profits. High protein and fiber contents soybean meal and soybean hulls could increase the revenues of whole industry.

This study will focus on expelling process. The products of oil extraction include soybean oil, soybean meal and soy hulls which can be converted into mainly biodiesel and other applications such as animal feeds. The goal of this study is to set up the economics criteria of oil extraction for industrial scale, and that is not only used in biodiesel production, but expand the oil industries to multiple aspects simultaneously.

Materials and Methods

Computer Model

SuperPro Designer v9.0 (Intelligen, Inc., Scotch Plains, NJ) was applied to conduct the expelling process of soybean oil extraction. That allows the processing characteristic, equipment and economic parameters to be defined along with conditions, capacity and characteristic for each stream (Wood et al., 2014). Additionally, the environmental impact (wastes, total organic carbon (TOC), chemical oxygen demand (COD), theoretical oxygen demand (ThOD), biochemical oxygen demand (BODu, BOD5)) also can be conducted.

According the soybean process TEA model established by USDA (Haas et al., 2006), the oil expelling included three main processes (Figure 1), they were soybean (crops) handling, soybean oil handling and degumming (water degumming), and coproducts (soybean meal and soybean hulls) handling. The total capacity of soybean handling was 200,000,000 kg/year, and the final oil productivity was 27,000,000 kg/year with the total oil extraction rate of 72%.

Simulation

This study was conducting the analysis of expelling process from 1980 to 2014. That not only focused on the main product (soybean oil), but took coproducts (soybean meal and soybean hulls) into consideration (Table 1).

a. Independent factors
   Purchasing prices of soybean, market prices of soybean oil, meal (USDA ERS, 2014), hulls (Feedstuffs, 1980-2014) and utilities (electricity and natural gas) prices (EIA, 2014) were averaged every 10 years from 1980 to 2014.

b. Model assumptions
   The time of service of the model is 15 averaged, and loan interest was set at 7.0% per year. The equipment prices from 1980 to 2014 (Table 2) were estimated according to the CPI inflation index factor (Bureau of Labor Statistics, 2014), and the price from 2014 was taken as the base. And the construction period and start-up time are 30 and 4 months respectively.

For each simulation result, the fixed capital costs, the annual operation costs (AOC), the annual revenues and total profits were considered. The gross margin percentage could be obtained (Eq. 1).

$$Gross\ Margin\ (\%) = \frac{Revenues - Cost\ of\ good\ sold}{Revenue} \times 100\% \qquad Eq. 1$$

Table 1 Price input of materials and utilities for simulation.

	Soybean ($/kg)	Soybean meal ($/kg)	Soybean oil ($/kg)	Soybean Hulls ($/kg)	Natural Gas ($/MT)	Electricity ($/kwh)
1980-1989	0.228	0.220	0.489	0.060	0.053	0.047
1990-1999	0.217	0.210	0.494	0.060	0.057	0.047
2000-2009	0.255	0.255	0.618	0.120	0.166	0.057
2010-2014	0.476	0.481	1.023	0.208	0.121	0.068

Table 2 Facility prices used in simulation ($)

		1980-1989	1990-1999	2000-2009	2010-2013
Material handling	Screw conveyor	43649	62547	80064	95276
	Storage tank	1647627	2361003	3022229	3596444
	Drum dryer I.	58639	97606	107561	127998
	Grinder	78039	111827	143145	170343
	Drum dryer II.	35272	50543	64699	76991
Oil handling	Degumming Tank	110665	158580	202992	241559
	Dryer	22486	32221	41245	49082
Meal and hulls handling	Primary grinder	37035	53070	67933	80841
	Secondary grinder	68339	97928	125353	149170
Total Facilities		2101749	3025326	3855222	4587704

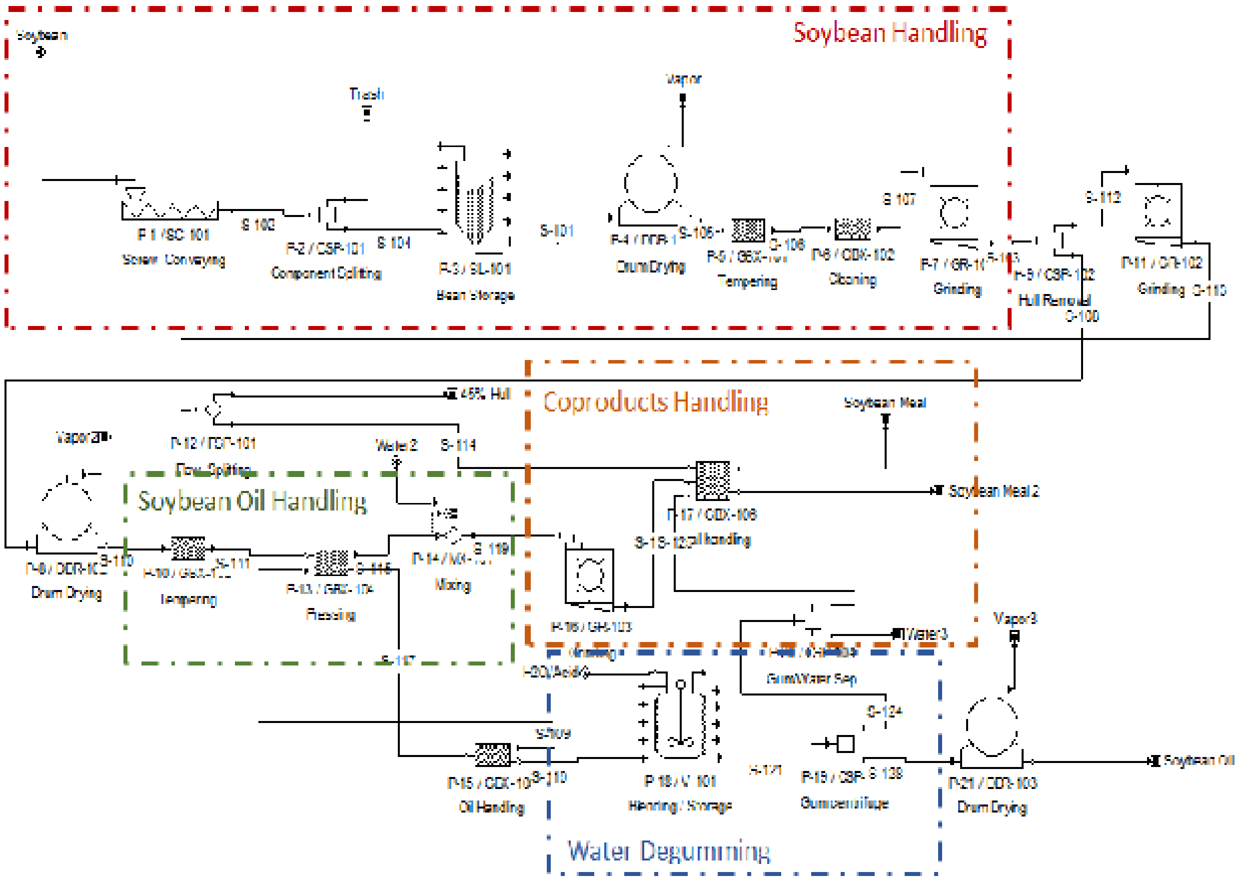

Figure1 The soybean oil expelling process model

Results and Discussion

Capital Costs

Capital costs comprise of direct fixed capital (DFC), working capital and startup cost. The DFC includes total plant direct cost (TPDC), total plant indirect cost (TPIC) and contractor's fee and contingency (CFC). For technic economic evaluation of a process, capital costs are the initial investment put into the plant (Wood et al., 2014). And TPDC and TPIC take the majority with around 70% of the capital costs estimation (Figure 2). That contains equipment costs, processing piping, instrumentation, building, insulation, electrical work, engineering and construction costs (Table 3).

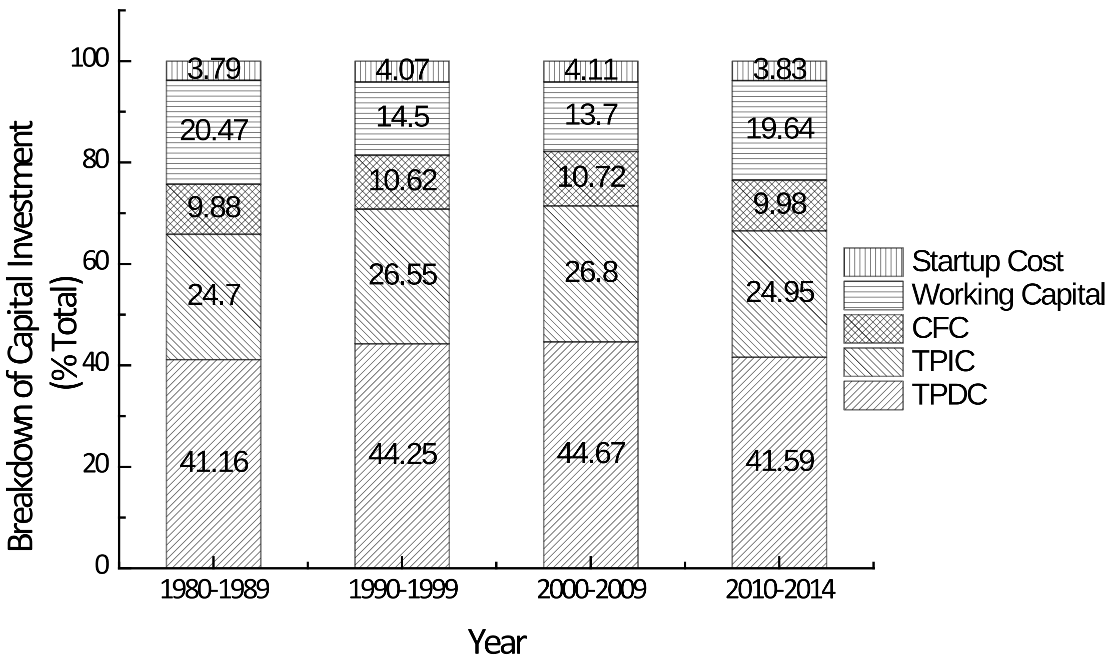

Figure 2 Breakdown of total capital investment

Table 3 Average total capital investment during different periods between1980 and 2014.

		1980-1989	1990-1999	2000-2009	2010-2014
TPDC	Equipment Purchase	2700000	3904000	4953000	5894000
	Installation	482000	708000	885000	1053000
	Processing Piping	945000	1366000	1734000	2063000
	Instrumentation	1080000	1561000	1981000	2358000
	Insulation	81000	117000	149000	177000
	Electrical	270000	390000	495000	589000
	Building	1215000	1757000	2229000	2653000
	Yard Improvement	405000	586000	743000	884000
	Auxiliary Facilities	1080000	1561000	1981000	2358000
	Total TPDC	8258000	11950000	15150000	18029000
TPIC	Engineering	2065000	2988000	3788000	4507000
	Construction	2891000	4183000	5303000	6310000
CFC	Contractor's Fee	661000	956000	1212000	1442000
	Contingency	1322000	1912000	2424000	2885000
DFC	TPDC+TPIC+CFC	3806000	5505000	6981000	8307000
	Working Capital	4108000	3917000	4645000	8515000
	Startup Cost	760000	1099000	1394000	1659000
Total	DFC+Working Capital +Startup cost	20,065,000	27,005,000	33,916,000	43,347,000

Equipment cost, which takes about 33% of total TPCD is also the fundamental of other costs including installation, processing piping, instrumentation, insulation/electrical and so on. However, the equipment cost also increases or decreases with different scales of streams. Besides DFC, the working capital and startup cost were included in the total capital cost. They are also affected by the scales, equipment and economic conditions in the year when the plant is built up. In this study, the total capital investment takes 30-35% of whole costs when the operating cost and total capital investment were considered.

Annual Operating Costs

The annual operating costs of soybean oil expelling process is comprised of the fees associated with facilities, utilities and materials (Figure 3). According to the result, the materials play the critical factor which take over 85% of all annual operating costs affect the revenues and net profit. Utilities and Facility take about 2-4% and 6-10% individually.

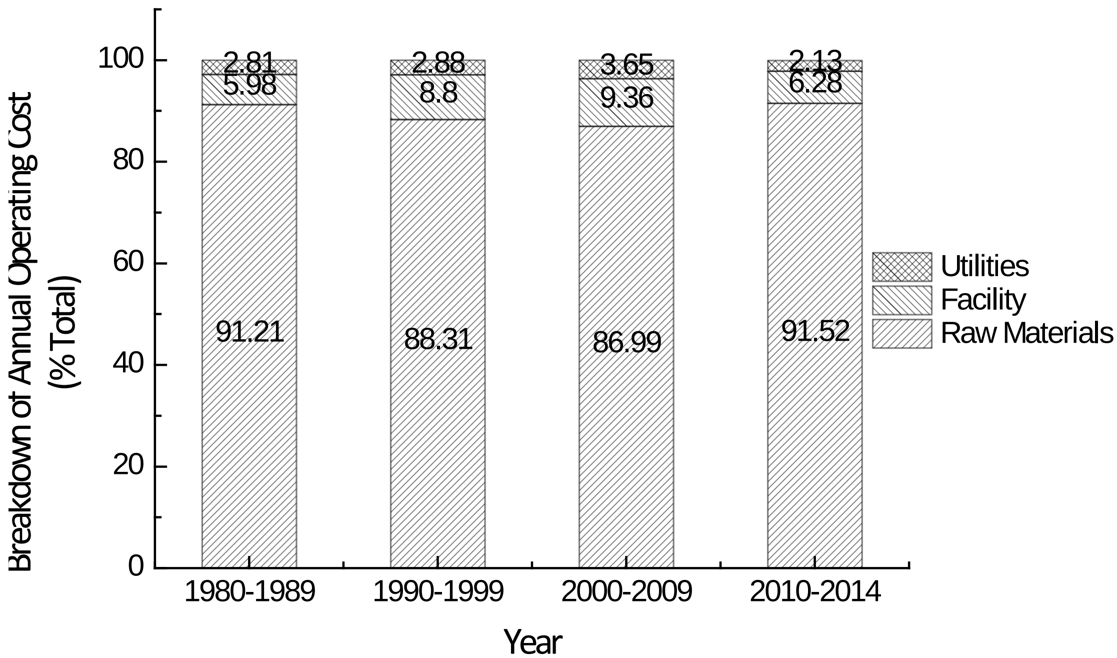

Figure 3 Breakdown of annual operating cost of soybean expelling process.

I. Materials

In this study, expelling is a physical process, and the water degumming was applied. Hence, there are no other chemicals which were used. Soybean is the major resource of material cost. That indicates the material cost is highly corresponding to the purchasing price of soybean. And the fluctuation of soybean price is shown in Figure 4. From the price changes with year, that also associates with the proportion of materials cost. The prices has increased rapidly since 2005, and that is the reason why that leads material costs to an important factor in the whole process.

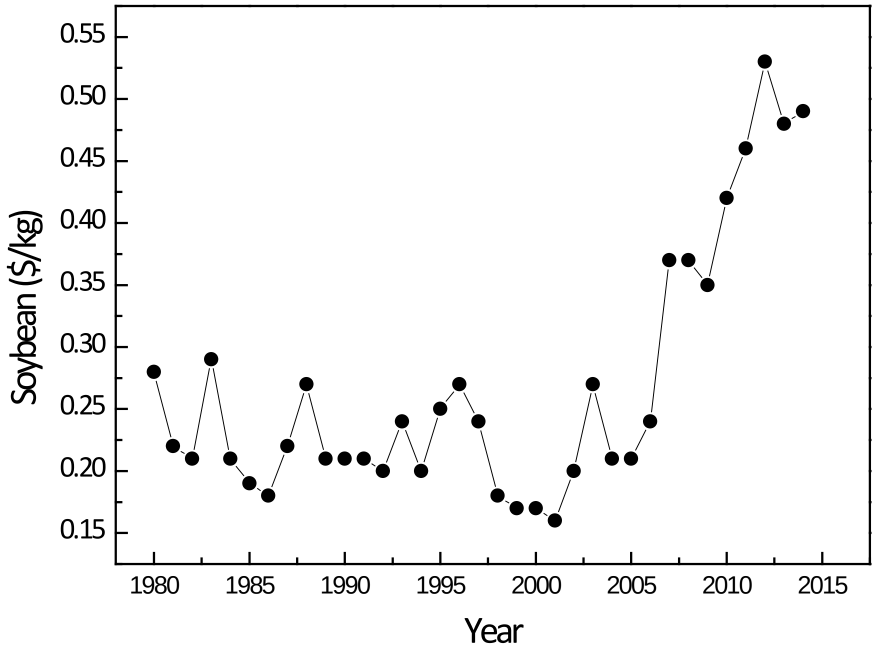

Figure 4 The trend of soybean price from 1980 to 2014 (USDA ERS, 2014)

I. Facilities and Utilities

Facility cost includes maintenance expenses, equipment depreciation, insurance, taxes, and miscellaneous expenses. In this model, the maintenance fee was only considered as 10% of the equipment purchasing price. The facilities expense is from 5-10% of the annual operating cost. Compared to materials and facilities cost, the utility expenses are relatively low, that only comprises 2-4% of total annual operating cost. Figure 5 represents the proportion of utilities expenses. That includes natural gas, electricity, chilled water and steam. In the expelling process, natural gas and electricity are two major resources because there is no extra chemical reactions taking place in the process. From the result, the electricity cost is at least triple than natural gas cost. This condition is also relative to their purchasing prices (Figure 6).

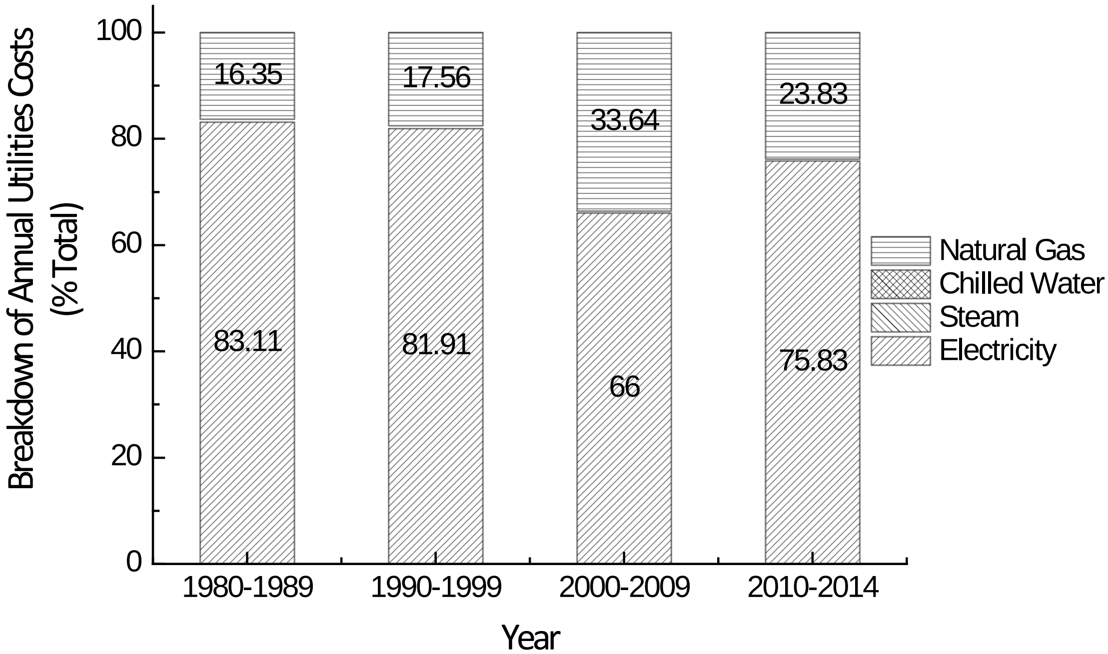

Figure 5 Breakdown of utility expenses of annual operating cost

We can find that the natural gas cost increased to about 34% and the electricity cost decreased to 66% during the period from 200-2009. During these ten years, the difference between average electricity and average natural gas price increased dramatically due to the natural gas price had increased significantly. According to the price fluctuations, that could provide a moderate reference for evaluating and predicting annual operating cost of the production stream.

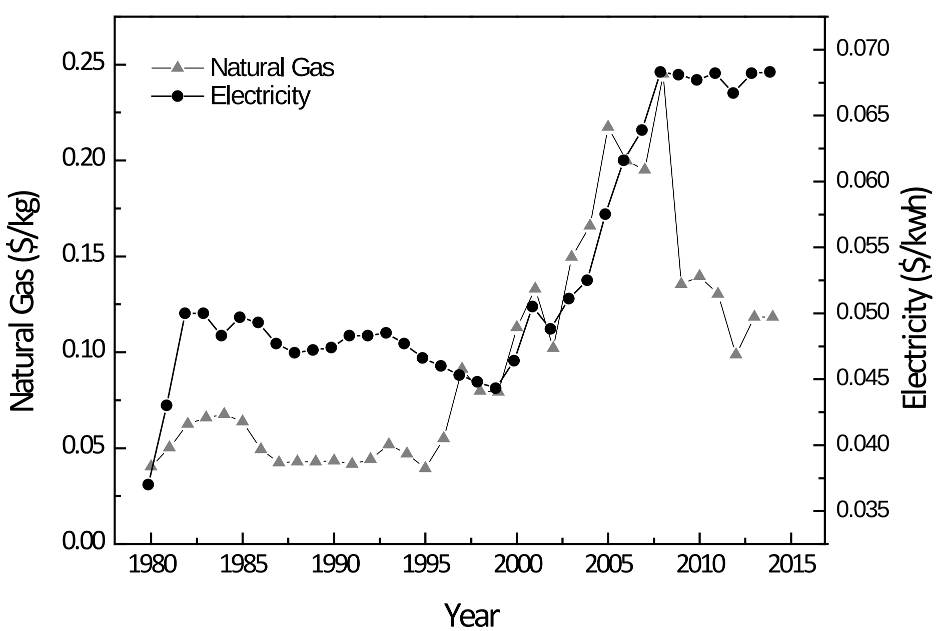

Figure 6 Prices of natural gas and electricity from 1980 to 2014 (EIA, 2014)

Annual Revenues

In this model, soybean oil, soybean meal and soybean hulls were counted as revenues. And the annual revenues were calculated according to these three products. The prices of soybean oil, soybean meal and soybean hulls from 1980-2014 (Figure 7) were used for the simulation. And the productivities of soybean oil, meal and hulls are 25,456,096 kg/yr, 153,991,461 kg/yr and 6,346,123 kg/yr respectively. The average annual revenue of 1980-1989, 1990-1999, 2000-2009 and 2010-2014 are 46,706,003 $/yr, 45,304,137 $/yr, 56,582,094$/yr and 101,420,000 $/yr individually.

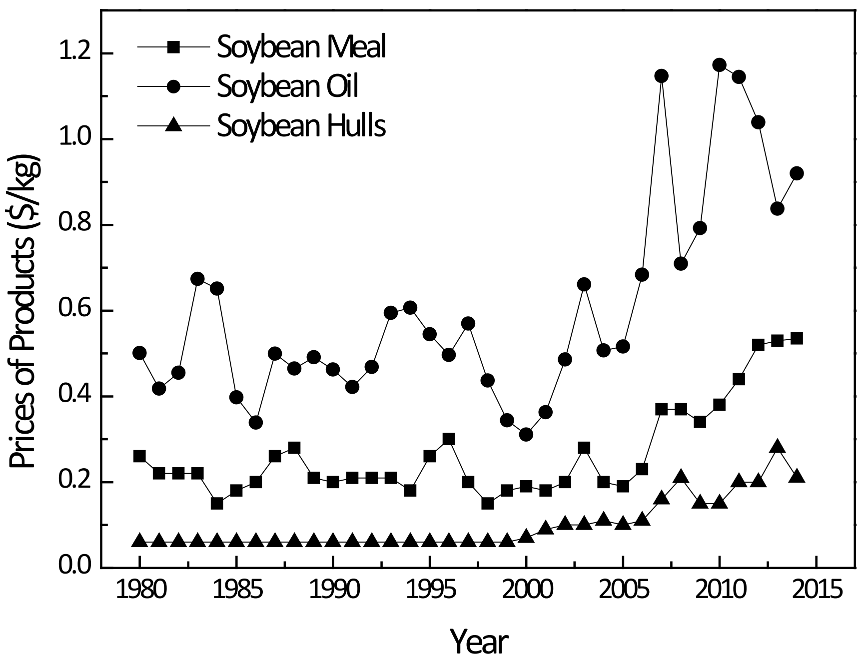

Figure 7 The selling prices of Soybean meal, oil and hulls from 1980 to 2014 (USDA ERS, 2014, Feedstuffs, 1980-2014)

I. Soybean Oil

The composition of soybean which comprised of 0.47% gum, 7.67 hulls, 59.46 % meal, 18.57% oil, 13% water and 0.83% other solids. According the result of simulation, 72% oil yield was obtained. Depending on the average selling price of soybean oil every 10 years from 1980 to 2014, the oil annual revenues of 1980-1989, 1990-1999, 2000-2009 and 2010-2014 are 12,447,115 $/yr, 12,585,163 $/yr, 15,780,780 $/yr and 26,035,757 $/yr separately. And the proportion of soybean oil and other products are shown in Figure 8.

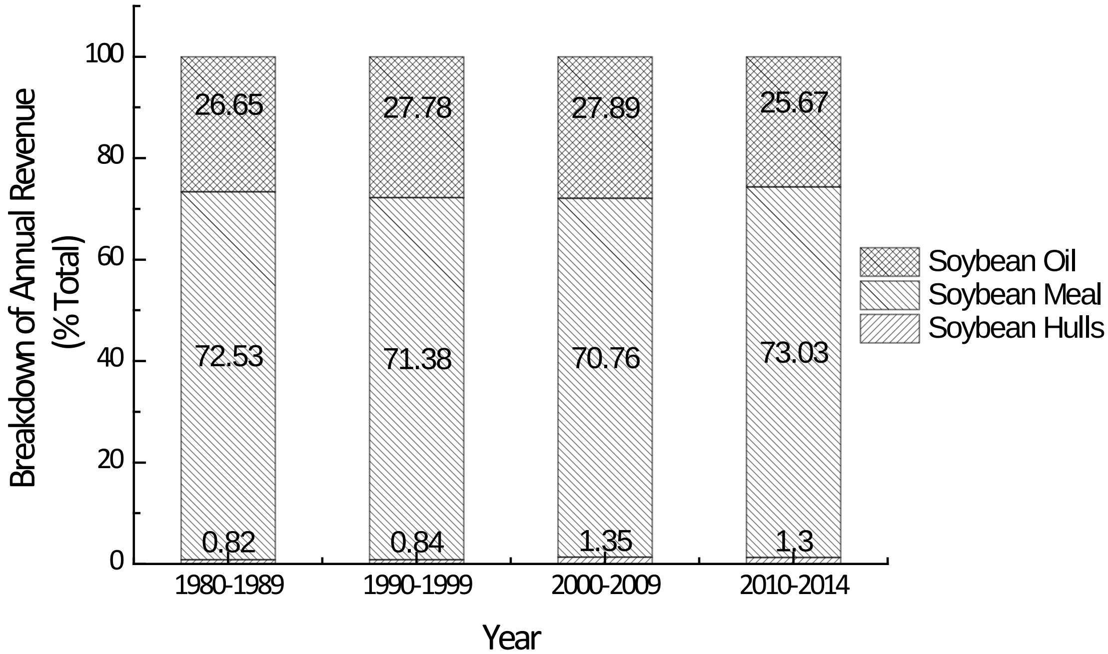

Figure 8 Breakdown of annual revenues fromsoybeans

The annual revenues from soybean oil ranges from 26% to 28%. Though the soybean is the main product of the production stream due to its high unit price, but that only takes about 19% composition of soybean compared to 60% of soybean meal. That's why soybean could not provide the major resource of revenues.

II. Soybean meal

According to Figure 8, soybean meal provides the major revenues ranging from 70% to 73% for the whole production stream due to its highest composition about 60%. The average revenues from 1980-1989, 1990-1999, 2000-2009 and 2010-2014 are 33,878,112 $/yr, 32,338,206 $/yr, 40,037,780 $/yr and 74,063,733 $/yr. When soybean was regarded as a coproduct that could improve the total revenue significantly.

III. Soybean Hulls

Soybean hulls have the small composition (about 7.5%) in soybean, which provided the smallest part to total revenues around 1%. The average revenues from 1980-1989, 1990-1999, 2000-2009 and 2010-2014 are 380,767 $/yr, 380,767 $/yr, 761,535 $/yr and 1,321,009 $/yr individually. Though soybean hulls do not have the competitive economic value as soybean oil, but that is a good resources of animal feeds due to its high fiber content. Because of this reason, the separation of soybean hull have been getting attraction recently.

IV. Gross Profits

Gross profit is defined as the annual operating costs subtracted from the annual revenues. The comparisons and relations among capital cost, annual operating costs, annual profits and gross profits are shown in Figure 9.

According the results above, the facilities costs increases every year with CPI inflation index factor, the annual operating costs increases depending on the materials prices which relative to economic condition, the utilities cost is another factor in operating costs. For the prices of natural gas, that had increased rapidly after 2000 from 0.057 $/kg to over 0.12 $/kg; by contrary, the prices of electricity ranges from 0.04 $/kwh to 0.06 $/kwh.

With the increase in market prices of products, the annual revenues have been increasing from 1980-2014. These trends can be observed in Figure 9. Under these conditions, if the plant was established during 1980-1999, the gross profits were negative; however, this process started to earn money after 2000 due to the market prices of products increase significantly at least double than the prices during 1980-1999.

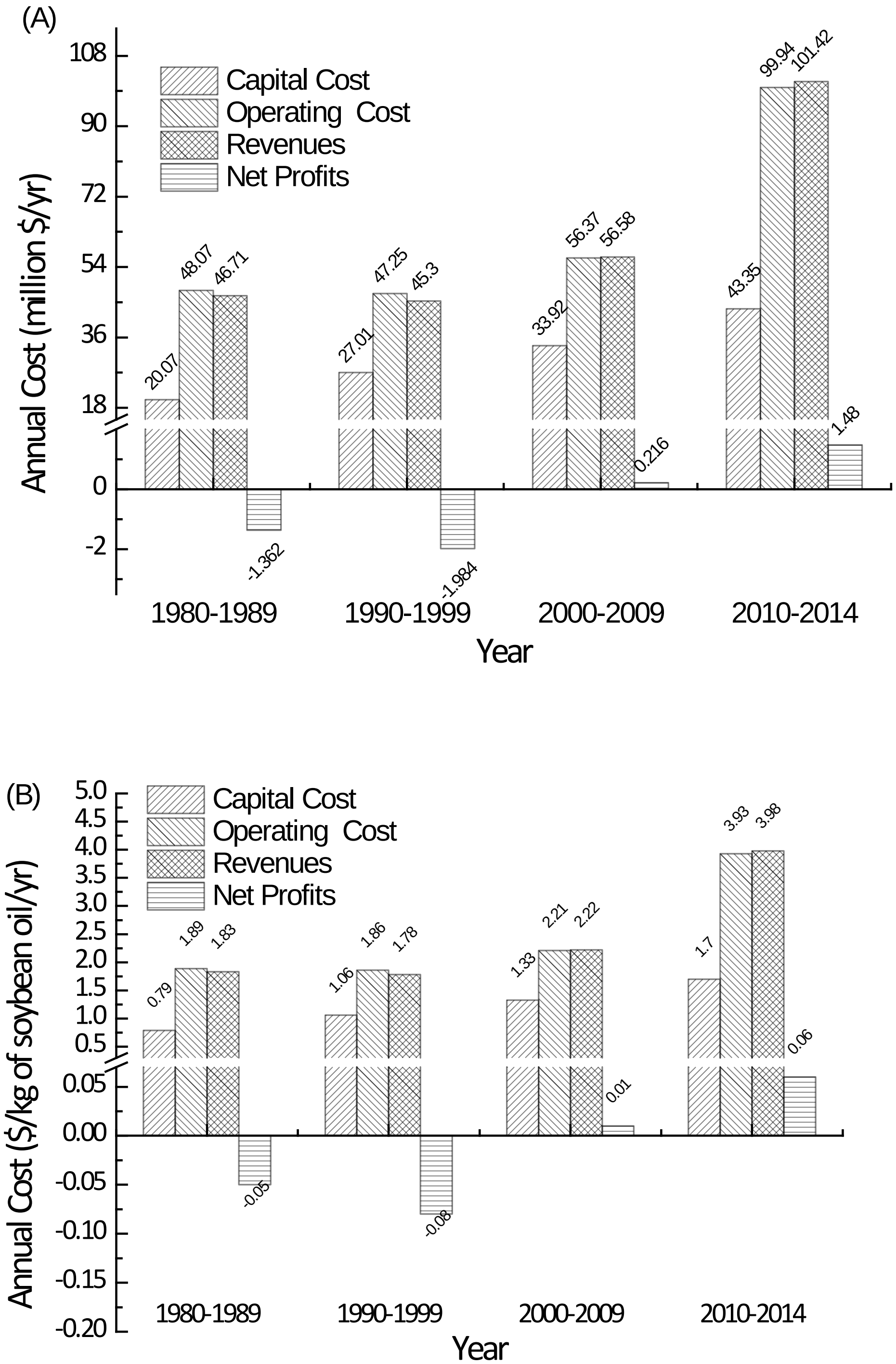

Figure 9 Comparisons of capital cost, operating cost revenues and profits. (A) Cost accumulated for a year of production. (B) Cost per 1 kg of soybean oil production.

Otherwise, the unit cost and unit gross profits were also conducted based on 1 kg soybean oil production (Figure 9 B). That indicates how much money has to be paid and earned for and from 1 kg soybean oil production. From the results, the negative profits were obtained from 1980-1999 as well. Especially from 1990-1999, the profits decreased to -0.08 $/kg of soybean oil/yr. As looking at the DFC, the cost had increased about 35% from 1980-1999, however, the market selling prices had not increased but decreased. That leads to lower the annual revenues from 1.83 $/kg of soybean oil/yr to 1.78 $/kg of soybean oil/yr. But the conditions after 2000, though the total capital investments have been increased around 25% every 10 years, the market selling prices of products have been increasing with larger range about 200% to 300%. That results in the increasing in gross profits to the highest during 2010-2014 with 0.06 $/kg of soybean oil/yr. In the period from 2000-2009, the gross profit was 0.01 $/kg of soybean oil/yr, that also indicate that condition was close to break-even point.

Additionally, the gross margin and payback time (Table 4) were conducted as well. The gross margin is defined as the ratio of the gross profits to revenues. And, the payback time indicates how many years that are needed to earn profits from production stream. According to the results, the negative gross margin values were given when starting up the plant before 2000. Besides, though the payback time could still be obtained, they are large enough that barely to earn the money back. For the conditions from 2000-2014, the gross margin values 0.38% and are 1.46%, and the payback times are 12.21 and 10.73 years separately. In this model, the service time is 15 years, so there is the feasibility of this process to make profits during the service time.

Table 4 Economic summary of soybean oil expelling process

	1980-1989	1990-1999	2000-2009	2010-2014
Capital Investment ($)	20066000	27006000	33915000	43347000
Operating Costs ($/yr)	48068000	47251000	56366000	99940000
Revenues ($/yr)	46706000	45304000	56582000	101420000
Gross Profits ($)	-1362000	-1948000	216000	1480000
Gross Margin (%)	-2.92	-4.3	0.38	1.46
Payback Time (yr)	244.28	190.34	12.21	10.73

Conclusions

The soybean expelling process consists of soybean handling, soybean oil handing and degumming and coproducts handling sections. For all products, soybean meal have the largest proportion of total revenues due to its high content around 60% in soybean. Hence, as soybean meal and hulls are also included in the production stream, that will improve the revenues significantly. Otherwise, the fluctuation of DFC and material costs affect the gross profits remarkably. In this project, if the plant was constructed in the condition similar to 1980-1999, the negative was obtained due to the lower selling market prices of products. After 2000, the market selling price have been increasing, that leads to the positive profit which indicate that there is the feasibility of the production. For expelling process, that is a kind of physical approach, and no chemicals and reaction involved in the process. The wastes of the production stream come from materials, and the GHG emissions are from utilities application basically. There is still a challenges to increase the efficiency and reduce the GHG emissions for the physical process.

References

Bureau of Labor Statistics. CPI Inflation Calculator. http://www.bls.gov/data/inflation_calculator.htm

Bender, M. (1999). Economic feasibility review for community-scale farmer cooperatives for biodiesel. *Bioresource Technol.,* 70,81-87.

Corley, R. N., III,Woldeghebriel, A., Corley, M. M., & Murphy,M. R. (1999). Effect of ethanol

concentration and application period of soyabean meal on the kinetics of ruminal

digestion. *Anim. Feed Sci. Technol*., 79, 247–254.

Chen, J.W., Wu, & W.T. (2003). Regeneration of immobilized *Candida Antarctica* lipase for transesterification. *J. Biosci. Bioeng.,* 95(5), 466-469.

Cheng, Z., & Hardy, R.W. (2003). Effects of extrusion and expelling processing, and microbial phytase supplementation on apparent digestibility coefficients of nutrients in full-fat soybeans for rainbow trout (Oncorhynchus mykiss). *Aquaculture.* 218, 501514

U.S. Energy Information Administration. http://www.eia.gov/electricity/

Feedstuffs. 1980-2014. Minneapolis Miller Pub. Co. MN, USA.

Freedman, B., Butterfield, R. O., & Pryde, E.H. (1986). Transesterification kinetics of soybean oil. *J. Am. Oil Chem. Soc.,* 63, 1375-1380.

Fukuda, H., Konda A., & Noda, H. (2001). Biodiesel fuel production by transesterification of oils. J. Biosci. Bioeng. 92 (5), 405-416.

Hass, M.J., McAloon, A.J., Yee, C.Y., & Foglia, T.A. (2006). A process model to estimate biodiesel production costs. *Bioresource Technol.,* 97,671-678.

Haas, M., Yee, W., & McAloon, A. (2006). USDA soybean pressed processing model. PA, USA.

Hama, S. Yamaji, H., Fukumizu, T., Numata, T., Tamalampudi, S., Kondo,A., Noda, H., & Fukuda, H., (2007). Biodiesel-fuel production in a packed-bed reactor using lipase-produing *Rhizopus oryzae* cells immobilized within biomass support partcles. *Biochem. Eng. J.,* 34, 273-278.

Koutinas, A.A., Chatzifragkou, A., Kopsahelis, N., Papanikolaou, S., & Kookos, I.A. (2014). Design and techno-economic evaluation of microbial oil production as a renewable resource for biodiesel and oleochemical production. *Fuel. 116,566-577*.

Lynch, G. L., Berger, L. L., Merchen, N. R., Fahey, G. C., Jr., & Baker, E. C. (1987). Effects of

heat and alcohol treatments of soybean meal on nitrogen utilization by sheep.

J. Anim. Sci., 65, 235–243.

Li, H., Pordesimo, L., & Weiss, J. (2004). High intensity ultrasound-assisted extraction of oil

from soybeans. *Food Res. Int*., 37, 731–738.

Marchetti, J.M., Miguel, V.U., & Errazu, A.F. (2008). Techno-economic study of different alternatives for biodiesel production. *Fuel Process. Technol.*, 89, 740-748.

Marchetti, J.M., & Errazu, A.F. (2008). Technoeconomic study of supercritical biodiesel production plant. *Energy Convers. Manage.*, 42, 2160-2164.

Mlay,H., Katima, J.H.Y., & Minja, R.J.A. (2014). Modifying plant oils for use as fuel in rural contexts Tanzania: Techno-Economic analysis. *O. J. M. Si.,* 2,43-56.

Nelson, R.G., Howell, S.A., Weber, J.A. (1994). Potential feedstock supply and costs for biodiesel production. In: Bioenergy 94' proceedings of the sixth national bioenergy conference.

Noordam, M., Withers, R. (1996). Producing biodiesel from canola in the inland northwest: an economic feasible study Idaho agricultural experiment station bulletin No 785.

Noureddini, H., & Zhu, D. (1997). Kinetics of transesterification of soybean oil. *J. Am. Oil Chem. Soc.,* 74, 1457-1463.

Oliveira, R. C., Barros, S. T. D., & Gimenes, M. L. (2013). The extraction of passion fruit oil

with green solvents. *J. Food Eng.*, 117, 458–463.

Riva, A., D'Angelosante, S., & Trebeschi, C. (2006). Natural gas and the environmental results of life cycle assessment. *Energy.* 31, 138-148.

Ranganathan, S.V., Narasimha, S.L., & Muthukumar, K. (2007). An overview of enzymatic production of biodiesel. *Bioresource Technol.* 1010-1016.

Spath, P.L., & Mann, M.K. (2002). Environmental aspect of producing electricity from a coal-fired power generation system-A life cycle assessment. National Renewable Energy Laboratory, USA.

SoyStats (2013). Available in: http://www.soystats.com (Accessed in: November 29

2013)

Sawada, M.M., Venâncio, L.L., Toda,T.A., & Rodrigues, E.C. (2014). Effects of different alcoholic extraction conditions on soybean oil yield, fatty acid composition and protein solubility of defatted meal. *Food Res. Int.,* 62, 662-670.

Tabtabaei, S., & Diosady, L. L. (2013). Aqueous and enzymatic extraction processes for the

production of food-grade proteins and industrial oil from dehulled yellow mustard

flour. *Food Res. Int.,* 52,547–556.

United States Department of Agriculture Economic Research Service (USDA ERS). (2014). Soybean and Oil crops. http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/related-data statistics.aspx

Watanabe, Y., Shimada,Y., Sugihara, A., Noda, H., Fukuda, H., & Tominaga, Y. (2000). Continuous production of biodiesel fuel from vegetable oil using immobilized *Candida Antarctica* lipase. *J. Am. Oil Chem. Soc.,* 77,355-360.

Zhang, Y., Dubé, M.A., McLean, D.D., & Kates, M. (2003). Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis. *Bioresource Technol.,* 90,229-240.